# NOVEL METHOD FOR NUMERICALLY ACCURATE ANALYSIS OF PRINTED ROTMAN LENS ANTENNAS

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## ABSTRACT

Broadband multiple beam electronically scanned antennas are a key component of the Future Combat Systems, where heavy armor is traded in by active protection systems, and various radar and communications capabilities are integrated into a single Multi-Function RF system. Due to their inherent broadband properties, Rotman lenses have received attention in applications. However, these lenses are electrically large structures, making it difficult to be simulated with reasonable accuracy so that a quick design and fabrication can be achieved. In this paper, we present a novel hybrid technique for the analysis of printed lenses that offers tremendous savings in the required computational resources, when compared to the existing general 3D and 2D electromagnetic simulation tools.

## 1. INTRODUCTION

Various Rotman lenses find their application as beam-forming networks in the implementation of the electronically steered antennas, due to their broadband nature, low cost and simplicity, compared to the traditionally used electronic phase shifters. Various Rotman lens designs are being considered for Ka-band antenna systems for the US Army and considerable effort has been focused on the design and analysis of the lens for such systems (Kilic and Weiss, 2004). The lens can be designed using classical formulas based on geometrical optics, (Rotman and Turner, 1963; Rappaport and Zaghloul, 1985; Hansen, 1991). In recent years, more attention has been given to accurate procedures that take into account the effect of the mutual coupling between the lens ports. However, there is a lack of suitable computational tools for the characterization of electrically large structures, such as the Rotman lenses, that include the effects of fringing fields and port mutual couplings. In this paper we present a novel hybrid technique for the analysis of printed lenses that is numerically accurate, and at the same time orders of magnitude faster than the available planar (2D) electromagnetic (EM) simulators.

## 2. NOVEL HYBRID METHOD FOR PRINTED LENSES

The printed lens antenna shown in the Figure 1 is a Ku-Band prototype design developed at U.S. Army Research Laboratory. The structure can be modeled using full wave solution approaches. However, this involves significant computational overhead since one must model the lens itself, as well as the dielectric substrate. A better approach is to use a 2D MoM simulator. In that case, the contribution of the grounded dielectric slab is implicitly included in the analysis, and one only models the metallic parts of the structure on top of the dielectric (Figure 2). The reduction in the number of unknowns required for the analysis is about 2.5 times, versus the 3D EM computation, which translates into 5 times reduction in the required memory and 10 times faster computation.

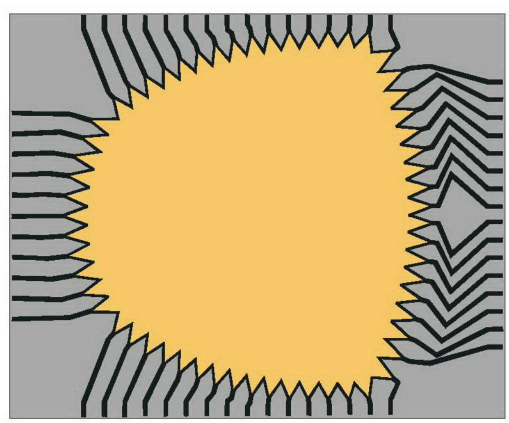

Figure 1. Modeling of the printed lens using 3D electromagnetic simulators.

# Report Documentation Page

*Form Approved*
*OMB No. 0704-0188*



| 1. REPORT DATE | 2. REPORT TYPE | 3. DATES COVERED |
|---|---|---|
| **00 DEC 2004** | **N/A** | **-** |

4. TITLE AND SUBTITLE
**Novel Method For Numerically Accurate Analysis Of Printed Rotman Lens Antennas**

5a. CONTRACT NUMBER
5b. GRANT NUMBER
5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

5d. PROJECT NUMBER
5e. TASK NUMBER
5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
**Antenna Research Associates, Inc., Beltsville, MD 20705; U. S. Army Research Laboratory, Adelphi, MD 20783; Virginia Polytechnic Institute and State University, Alexandria, VA 22314**

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR’S ACRONYM(S)

11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
**Approved for public release, distribution unlimited**

13. SUPPLEMENTARY NOTES
**See also ADM001736, Proceedings for the Army Science Conference (24th) Held on 29 November - 2 December 2005 in Orlando, Florida. , The original document contains color images.**

14. ABSTRACT

15. SUBJECT TERMS

| 16. SECURITY CLASSIFICATION OF: | | | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON |
|---|---|---|---|---|---|
| a. REPORT | b. ABSTRACT | c. THIS PAGE | | | |
| **unclassified** | **unclassified** | **unclassified** | **UU** | **4** | |

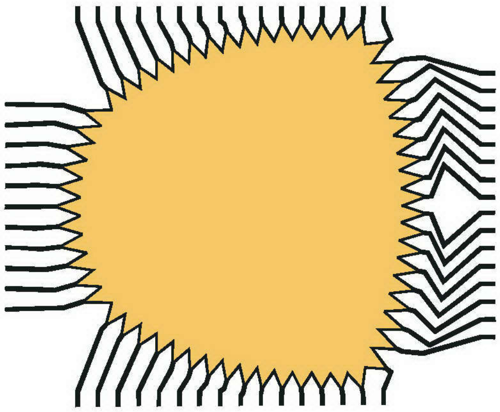

Figure 2. Modeling of the printed lens using 2D MoM electromagnetic simulator.

Additional improvements, compared with the 2D MoM simulation, can be obtained by exploiting the specific geometry of the printed lens. First, the symmetric nature of the lens can be utilized to reduce the problem size by half. Furthermore, the central part of the printed structure (white region in Figure 3) can be considered a part of a parallel-plate waveguide. The remaining metallic part of the lens is treated as a planar microstrip structure.

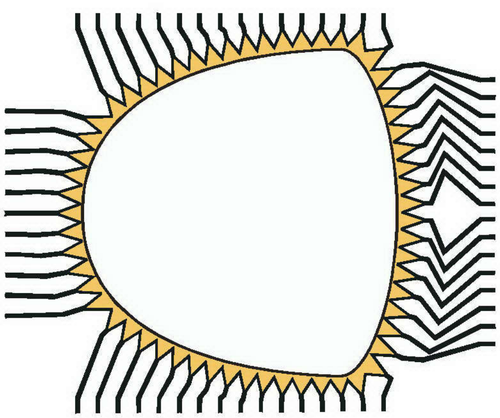

Figure 3. Modeling of the printed lens using novel hybrid MoM technique.

The continuity of the electric and magnetic fields between the two regions is achieved by placing a layer of equivalent electric and magnetic currents at the boundary between regions (perpendicular to the plane of paper). The electric and magnetic fields in the "microstrip region" come from the (real) electric currents on the metallic part of the structure in Figure 3, as well as from the equivalent currents at the boundary between regions. Because of the surface equivalence principle, the fields inside the "parallel-plate" region come only from the equivalent sources at the boundary. The fields inside a region are given by:

$$\mathrm{E} = \mathrm{j}\omega\mu\int_S \overline{\overline{G}}_{EJ}\cdot \mathrm{J}\,\mathrm{d}S - \int_S \overline{\overline{G}}_{EM}\cdot \mathrm{M}\,\mathrm{d}S,$$
$$\mathrm{H} = \int_S \overline{\overline{G}}_{HJ}\cdot \mathrm{J}\,\mathrm{d}S + \mathrm{j}\omega\varepsilon\int_S \overline{\overline{G}}_{HM}\cdot \mathrm{M}\,\mathrm{d}S, \tag{1}$$

where $S$ is the surface containing the electric and magnetic sources, and $\overline{\overline{G}}_{EJ}$, $\overline{\overline{G}}_{EM}$, $\overline{\overline{G}}_{HJ}$, and $\overline{\overline{G}}_{HM}$ are dyadic Green's functions for the "parallel-plate" or "microstrip" region. By equating the fields obtained from both sides of the boundary surface between regions, we end up with an integral equation with the unknown electric and magnetic currents, which is then solved by the traditional MoM approach. Using the hybrid approach, the number of unknowns can be reduced about four times, compared to the 2D MoM simulation, which translates into 16-fold reduction in the required memory, and about 60 times faster computation.

## 3. NUMERICAL EXAMPLE:

In order to test the applicability of the proposed numerical tool to electrically large structures, a simple test case was designed tos simulate an electrically large multiple port device. To simplify the initial analysis, one input port and three output ports are positioned multiple wavelengths apart and facing each other. If this problem can be solved accurately in a significantly reduced amount of time, then an estimate can be made in the amount of time and resources it would take to simulate the whole structure.

The four open-ended waveguides in the simulation rest above a 15.8cm x 15.8cm metallic plane, as shown in Figure 4. Standard Ku-band waveguides, with the cross-section of 1.58cm x 0.79cm, are shorted on one side and fed using a probe positioned 0.58 cm from the short.

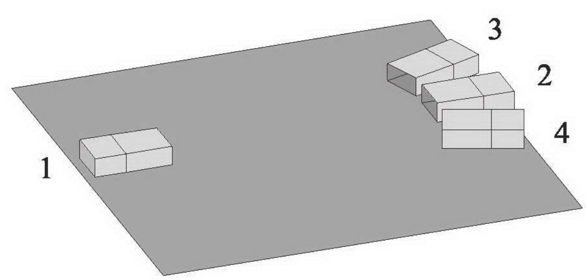


Figure 4. Four open ended waveguides above a large metallic plane.

The scattering matrix of this system was computed at frequencies ranging from 14 GHz to 18 GHz. The simulation was performed using both higher-order Method of Moments (Djordjevic and Notaros, 2004a), and the higher-order Method of Moments – Physical Optics method (Djordjevic and Notaros, 2004b). In the

hybrid analysis, the waveguides were modeled using MoM, while the ground-plane was analyzed using PO. In the frequency range of interest, the system was modeled using from 101 elements (at 14 GHz) to 133 elements (at 18 GHz), and the required number of unknowns varied from 2068 to 3288.

The magnitude and phase of the computed $S_{11}$, $S_{12}$, and $S_{13}$ parameters are shown in Figures 5, 6 and 7, respectively. Because of the symmetry of the system, $S_{13}=S_{14}$. It is observed that the two methods produce almost identical results for the $S_{11}$ parameter. The average absolute error for 21 frequencies analyzed was 0.9% for the magnitude and 0.5 degrees for the phase. Some discrepancy between the two sets of results for $S_{12}$ is observed (error of 4.7% in magnitude and 2.6 degrees in phase). The results for $S_{13}$ exhibit the largest mismatch (4.5% in magnitude and 10 degrees in phase). The hybrid analysis, however requires much less time; for example, at the frequency of 18 GHz, MoM analysis required 153, and MoM-PO analysis only 56 seconds at Dell Inspiron 4150 laptop computer.

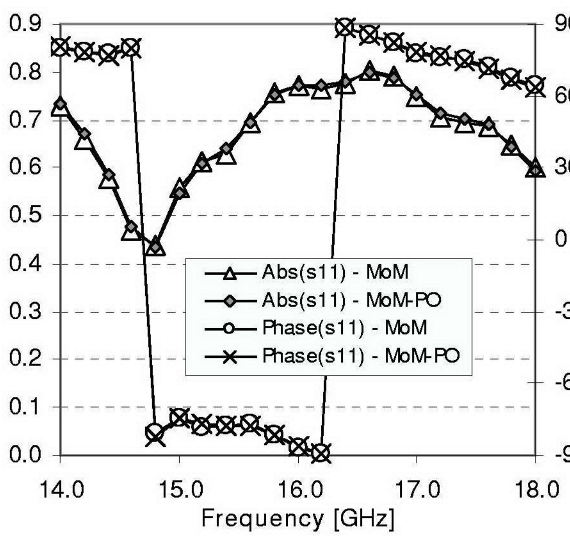


Figure 5. Computed $s_{11}$ parameter using MoM and MoM-PO

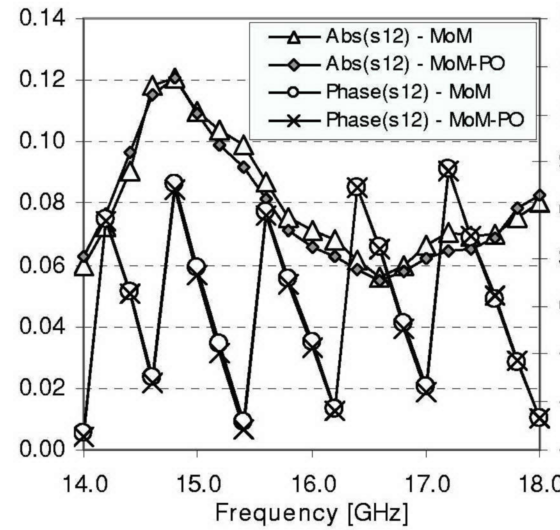


Figure 6. Computed $s_{12}$ parameter using MoM and MoM-PO

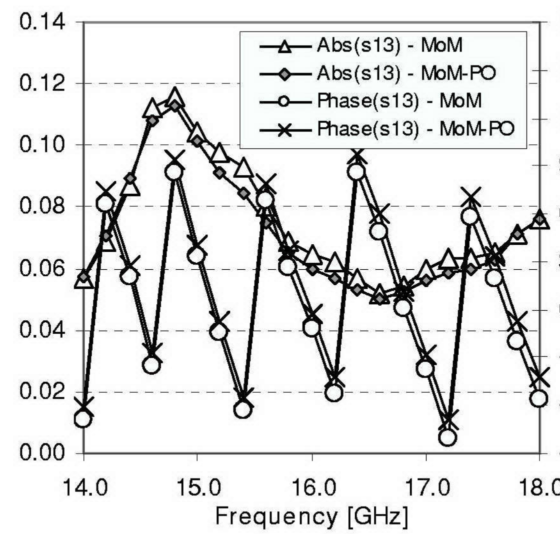


Figure 7. Computed $s_{13}$ parameter using MoM and MoM-PO

## CONCLUSION

A hybrid method for analysis of printed lens antennas was investigated in this paper. The approach makes use of physical properties of the system in order to reduce the required number of unknowns and, therefore, the computational resources required for the analysis. In specific, the central part of the printed structure is treated as part of the parallel-plate waveguide, and the rest of the metallization is treated using regular microstrip techniques. The coupling between the two regions is achieved by imposing the field continuity condition between these regions.

On a simple three-dimensional example, we have shown the advantages of the hybrid modeling techniques. With only slight reduction in accuracy, the computational time was decreased almost three times, which proves that novel hybrid computational technique renders itself as an indispensable tool for the design and analysis of electrically large structures.

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